Predicting accurate paediatric bone morphology for clinical gait analysis and musculoskeletal modelling

Laura Carman[1], Tim Salemink Waldren[1], Thor Besier[1], Julie Choisne[1]
[1]Auckland Bioengineering Institute, The University of Auckland, New Zealand
Email: laura.carman@auckland.ac.nz

Summary

Children with neuromuscular conditions face skeletal deformities that affect gait and stability. This study introduces an automated workflow to generate accurate pediatric musculoskeletal models from gait analysis data. Marker trajectories and ground reaction forces are filtered, key lower limb markers are extracted, and missing markers are extrapolated. A paediatric articulated shape model predicts bone geometry, enabling custom OpenSim model creation for kinematic and kinetic analysis. This workflow will aid clinical gait labs with streamlined, precise modeling.

Introduction

Skeletal growth in children is a dynamic process influenced by biological and mechanical factors. While typically developing children experience reasonably predictable changes in bone structure, those with neuromuscular conditions such as cerebral palsy or developmental hip dysplasia face altered skeletal development. These conditions can lead to deformities affecting hip stability, gait, and limb alignment [1]. Three-dimensional gait analysis is a critical tool for studying movement in such populations, enabling the development of targeted surgical interventions, orthoses, and rehabilitation plans [2]. However, creating accurate paediatric musculoskeletal models which closely represent medical imaging data is essential to fully leverage gait analysis data. We aim to create a workflow to automatically and accurately create paediatric musculoskeletal models.

Methods

The first step in this automated workflow is extracting the marker trajectories and ground reaction forces from the c3d gait analysis data. These are both low-pass filtered (8Hz) and resampled (100Hz). 12 lower limb motion capture markers are then extracted from the static trial (2x ASIS, 2x PSIS, 4x femoral epicondyles, 4x tibial malleoli). In the case where there is no medial knee marker, this is extrapolated from the lateral knee marker using a knee alignment device. The articulated shape model then predicts the left and right side lower limb bones through modifying PCA components and joint articulations [3]. The resulting bone geometries and landmark information are then used to generate a custom OpenSim model using the OpenSim python API. Inverse kinematics and kinetics are subsequently performed and graphically displayed to the user for interaction and interpretation.

Results and Discussion

Through this workflow, we were able to automatically generate a paediatric OpenSim musculoskeletal model and perform kinematic and kinetic analysis. Shown in table 1 is the RMSE, Dice score and volume error in the predicted bone geometries for the pelvis (P), femur (F), and tibia/fibula (TF) of the workflow predicted using the articulated shape model and compared to linear scaling of OpenSim adult bone geometries.

Table 1: RMSE, Dice score, and volume error of predicted bone geometries using the paediatric articulated shape model and linear scaling of adult bone geometry.

		Articulated shape model	Linear scaling adult	p-value
RMSE (mm)	P	2.63 ± 0.90	4.79 ± 1.39	< 0.001
	F	1.97 ± 0.61	4.38 ± 0.72	< 0.001
	TF	1.72 ± 0.51	4.39 ± 0.86	< 0.001
DICE SCORE	P	0.80 ± 0.06	0.56 ± 0.12	< 0.001
	F	0.90 ± 0.03	0.69 ± 0.05	< 0.001
	TF	0.88 ± 0.04	0.70 ± 0.04	< 0.001
Volume Error (%)	P	9.15 ± 7.86	30.54 ± 13.76	< 0.001
	F	8.47 ± 6.76	31.59 ± 10.02	< 0.001
	TF	10.00 ± 8.25	22.77 ± 15.43	< 0.001

Conclusions

We have developed a workflow to automatically generate paediatric musculoskeletal models from a static gait analysis trial. This workflow will be implemented in Australian and New Zealand gait labs to compute kinematic and kinetic outputs. Future work will involve testing the workflow on a pathological population with validation through medical imaging data. We will also add partial medical imaging data as an input to the shape model for improved representation of torsional deformities.

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